A New Improvement of Conventional PI/PD Controllers for Load Frequency Control With Scaled Fuzzy Controller

Aqeel S. Jaber, A. Z. Ahmad

Abstract— **Load Frequency Control (LFC) is one of the important issues in power system operation. The main objective of LFC is to keep the frequency and tie-line power close to their nominal values in case of disturbances. In this paper, two methods based on parallel adaptive of a scaled fuzzy with conventional technique to control the frequency of a power system is proposed. A particle swarm optimization (PSO) method is used to optimize the scales of fuzzy-PI/PD and gains tuning of PI/PD controllers. Two equal interconnected power system areas are used as a test system. As the results, the simulation has shown the effectiveness of the proposed controller compared with different PID and scaled fuzzy controllers in terms of speed response and damping frequency.**

Index Terms—**About four key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

The stability of both voltage and frequency were considered as a big issue in power system control. The matching of the total generation with the system losses and load demand is the criterion of successful operation of interconnected power systems [1]. Load Frequency Control is responsible for keeping the frequency into constant value, and decided the net power flow on tie-lines on a priori contract basis [2]. Therefore, it is important to have a good control of the net power flow on the tie-lines.

The main objective of LFC is keeping the frequency and tie-line power close to their nominal values in case of disturbance such as the generating unit is suddenly disconnected by the protection equipment and also for the large load that is suddenly connected or disconnected. Many LFC strategies have been developed and proposed, but most of them depending on the linear or non-linear control methods [3]. In order to control the frequency in power systems, various controllers have been used in different areas, but due to the non-linearity in system components and alternators, these developed feedback controllers could not efficiently control the frequency and rather slow for output response. The conventional controller such as PI and PID controller schemes will not reach a good performance [4] because the dynamics of a power system is inherently nonlinear, time invariant and governed by strong cross-couplings of the input variables. Therefore, the controllers have to be designed with taking into account the nonlinearities and disturbances.

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Recently the LFC systems use the proportional integral (PI) controllers in practice [5]. Static output feedback gains and linear matrix inequality are the most effective and efficient tool in control design, which stabilizes the system which used to calculate the gains of PID controller [6]. The robust adaptive control schemes also have been developed to deal the changes in system parametric [7]. Meanwhile the intelligent controller such as PID-ANN, PI-fuzzy and optimal control applied to LFC have been reported in [8]. Also, using genetic algorithm to scale the fuzzy-PI controller in LFC has been reported in [9]. In this respect, fuzzy control is the most suitable system in order to get promising results in case of a properly choosing of the memberships and rules [10].

Thus, in this paper, combination of scaled fuzzy-PI with a conventional PD controller; and scaled fuzzy-PD with conventional PI controller for LFC system are proposed. In most of the literature, the Fuzzy-PI and Fuzzy-PD controllers are more oscillation than the conventional PID controller. The fuzzy member ship shapes and control rules are selected depending on the system experts' experience [11]. This means, there are no rules that exactly can be used for input membership for unpredicted conditions (disturbances), which means the load frequency will not be considered. The proposed controller perhaps could solve this problem. The simulation results are carried out in term of frequency response on its damping under different load conditions and compared the effectiveness of proposed controllers with conventional PID and scaled fuzzy controller. The simulation results show that the oscillation, peak under shot and settling time with the proposed controller are better and guarantees the robust performance under a wide range of operating conditions.

II. THEORETICAL BACKGROUND

Power systems have a complex and multi-variable structures. It consists of many different control blocks, which is most of them are nonlinear and/or non-minimum phase systems [8]. Power systems are divided into control areas connected by tie lines. All generators are supposed to constitute a coherent group in each control area.

A. Load Frequency Control

Small changes in real power are mainly depended on the changes in rotor angle δ_r and, thus, the frequency f. The aim of LFC is to maintain real power balance in the system by controlling the frequency. When the real power demand changes, a frequency also will change, and in same way the change in load angle δr is caused by momentary change in generator speed. Therefore, LFC is non-interactive for small

changes and can be modelled and analyzed. This frequency error is amplified, mixed and changed to a command signal, which is sent to turbine governor. The governor operates to restore for balancing the power between the input and output by changing the turbine output. This method is also referred as Megawatt frequency or Power-frequency (P-f) control [9].

B. Fuzzy Controller

Nowadays fuzzy logic has been used in many sectors of industry including LFC [12]. The main goal of LFC in interconnected power systems is to protect the balance between production and consumption. Because of the complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions.

According to many researchers, there are some reasons for the present popularity of fuzzy logic control. First of all, fuzzy logic can be easily applied for most applications in industry. Besides, it can deal with intrinsic uncertainties by changing the controller parameters. On the other hand, their robustness and reliability make fuzzy controllers useful in solving a wide range of control problems [12]. Fuzzy logic shows experience and preference through its membership functions. These functions have different shapes depending on system experts' experience [13].

C. PSO Algorithm

PSO is introduced by Eberhart and Kennedy as a new heuristic method [14]. PSO is inspired by the food searching behaviors of fish and their activities or a flock of birds. In D-dimensional search space, the best individual position of particle *i* and the best position of the entire swarm are represented by

$$v_i(t+1) = \omega v_i(t) + c_1 r_1 (p_i(t) - X_i(t)) + c_2 r_2 (G(t) - X_i(t)) \quad (1)$$

$$X_i(t+1) = X_i(t) + v_i(t+1) \quad (2)$$

Where; $Pi = (pi1, pi2, \ldots, piD)$ and $G = (g1, g2, \ldots, gD)$, respectively, ω is inertia weight parameter and $c1$, $c2$ is acceleration coefficients. In each iteration of the PSO algorithm, the particles use the following equations to update their position (xi) velocity (v_i) [15].

D. Two Area of LFC Model

In many power systems model, the single area modeling can be summarized such in the following ways. The net power (ΔP) due to disturbance (ΔP_D) during power generation (ΔP_G) can be described as;

$$\Delta P = \Delta P_G - \Delta P_D \quad (3)$$

The changes could be absorbed by changing in kinetic energy (W_{kin},) of mass, load consumption and export of power (ΔP_{tie}). So, ΔP for i_{th} area can be obtained as follows;

$$\Delta P = 2\frac{W_{kin}}{f}\frac{\partial}{\partial t}(\Delta f) + D_i \Delta f_i + \Delta P_{tie\ i} \quad (4)$$

Where, D is power regulation and equal to $\Delta P/\Delta f$. By taking the Laplace transformation, yields;

$$[\Delta P_{Gi}(s) - \Delta P_{Di}(s) - \Delta P_{tie\ i}(s)]\frac{K_{Pi}}{1+sT_{Pi}} = \Delta F_i(s) \quad (5)$$

Where, $T_{Pi} = \frac{2H_i}{fD_i} sec$, H is inertia constant and f is the frequency. If the line losses are neglected, the individual $\Delta P_{tie\ ij}$ can be written as;

$$P_{tie\ ij} = \frac{|Vi||Vj|}{X_{ij}P_{ri}} sin(\delta i - \delta j) \quad (6)$$

The phase angle changes are related to the area of frequency changes, i.e.;

$$\Delta\delta i = 2\pi \int \Delta f_i dt \quad (7)$$

Thus, the power obtained is as follows;

$$P_{tie\ ij} = T_{ij} \int \Delta f_i dt - \int \Delta f_j dt \quad (8)$$

Where, $P_{tie} = 2\pi \frac{|Vi||Vj|}{X_{ij}P_{ri}} cos(\delta i - \delta j)$ and δ is load angle. Using upon Laplace transformation of (6), one gets;

$$\Delta P_{tie\ ij}(s) = \frac{T_{ij}}{s}[\Delta F_i(s) - \Delta F_v(s)] \quad (9)$$

Then, the transfer function of generator turbine (G_{tf}) can be obtained such as;

$$G_{tf} = \frac{1}{(1+sT_{Gi})(1+sT_{Ti})} \quad (11)$$

Where, T_T is turbine time constant and T_G is speed governor time constant. Therefore, the area of LFC in power system can be modelled as shown in Figure 1.

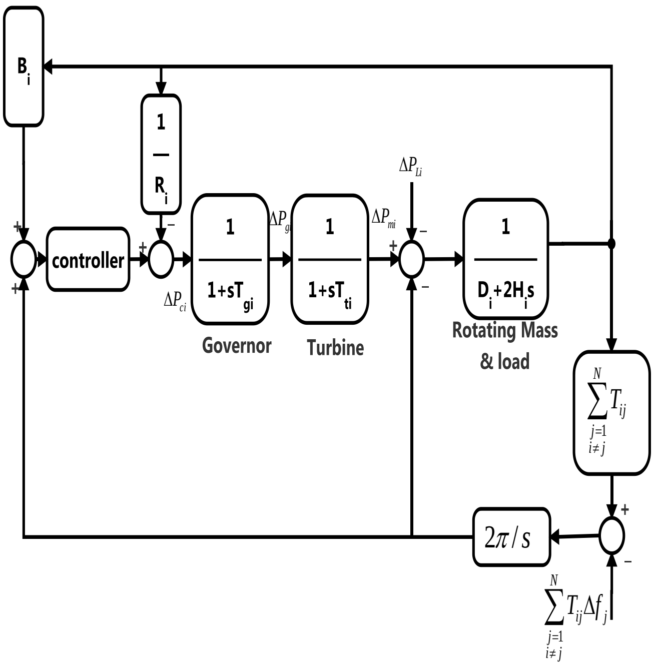

Figure 1: Block diagram for system of one area

The constant R_i is measured in Hz/pu MW for the static speed drop of the uncontrolled generator turbine. Meanwhile, $B_i = D + 1/R_i$. So, the block diagram of single area for two interconnected power system areas can be illustrated in Figure 2.

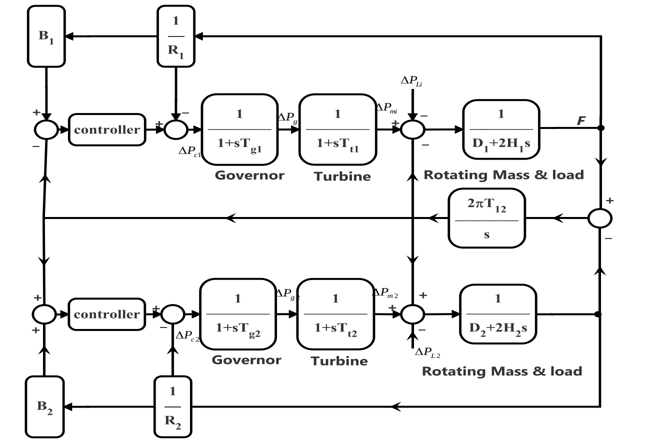

Figure 2: Block diagram for system area of two areas power system

III. PSO Scaled Fuzzy Controller

The boundaries of the membership functions are adapting with the input of the scaled fuzzy controller by using PSO by select the suitable gains (scaled optimized). These gains represented by three parameters, i.e., Gin1, Gin2 and Gout such shown in Figure 3. It is then defined the uncertain range by using PSO algorithms. The fuzzy rules have been designed as in Table 1, which based on the number of membership function from the inputs and the output (see Figure 4). Single input single output (SISO) of the fuzzy is proposed for this scaled fuzzy controller. The flow chart of PSO algorithm to optimize the scaled of fuzzy controller is shown in Figure 5.

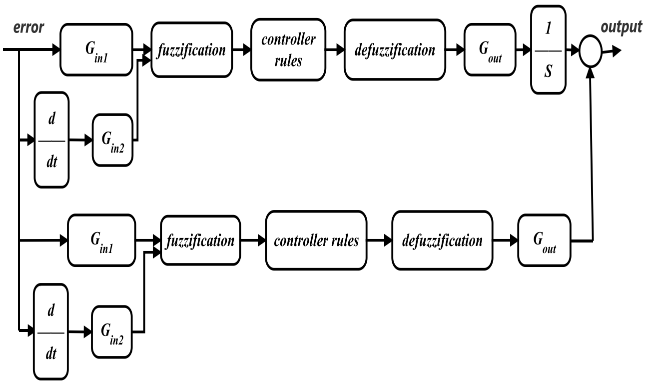

Figure 3: Scaled fuzzy-PI controller diagram

TABLE 1: Fuzzy Control Rules

$^{e}/_{\Delta e}$	MP	SP	Z	SN	MN
MP	MP	SP	SP	Z	Z
SP	SP	SP	Z	Z	NS
Z	SP	Z	Z	NS	NS
SN	Z	Z	NS	NS	MN
MN	Z	NS	NS	MN	MN

Where:
MP: medium positive, SP: small positive,
SN: small negative, Z: zero and MN: medium negative.

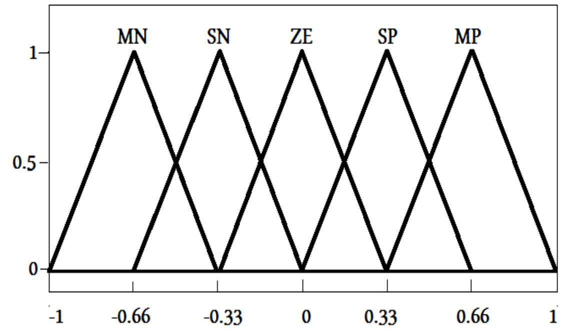

Figure 4: Membership function for input & output of fuzzy controller

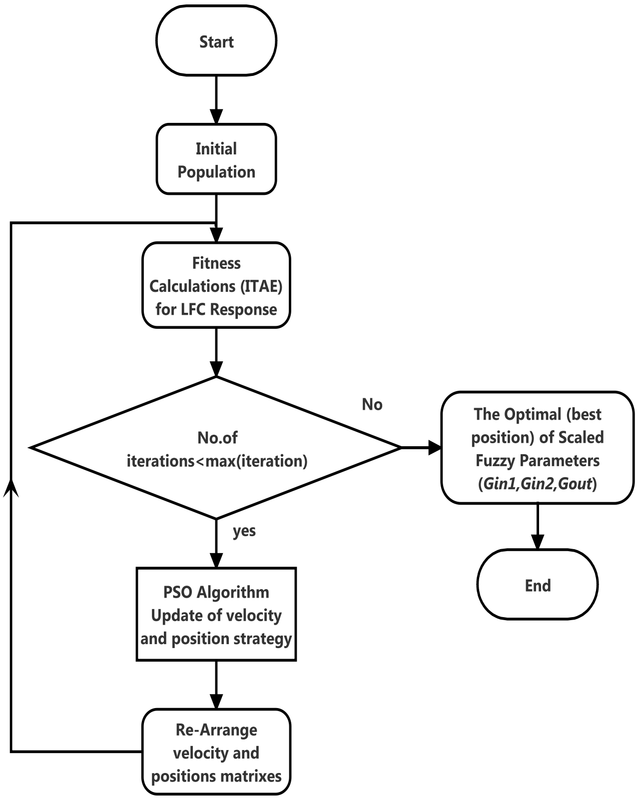

Figure 5: Scaled fuzzy parameter using PSO.

IV. Proposed Controller

The boundaries of the membership functions, which are adjusted based on expert experiences in the fuzzy methods may do not guarantee the system performances. To do so, the proper rules tuning must be carried out. In the case of disturbances, no specified fuzzy rules could be used and this might degraded the system performances. The addition of PI or PD controllers to fuzzy controller will guarantee that all of the conditions are under control. The gains tuning could be defined over an uncertain range and then will be obtained by using PSO algorithms.

A. Hybrid of fuzzy-PD with PI controller

The addition of PI to fuzzy PD is selected as a first method in parallel operation between fuzzy and conventional controller as shown in Figure 6. The value of PI is defined over an uncertain range and then obtaining by PSO algorithms.

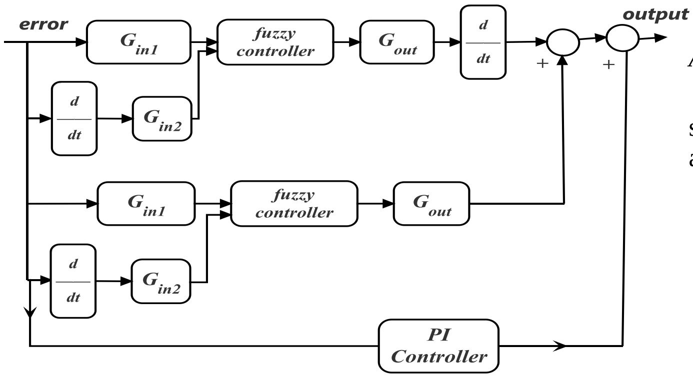

Figure 6: Fuzzy-PD with PI controller

B. Hybrid of fuzzy-PI with PD controller

The second approach is adapted the PD controller in series with scaled fuzzy-PI controller. With same procedures from first controller designing, the proposed parallel controllers can be seen in following Figure 7.

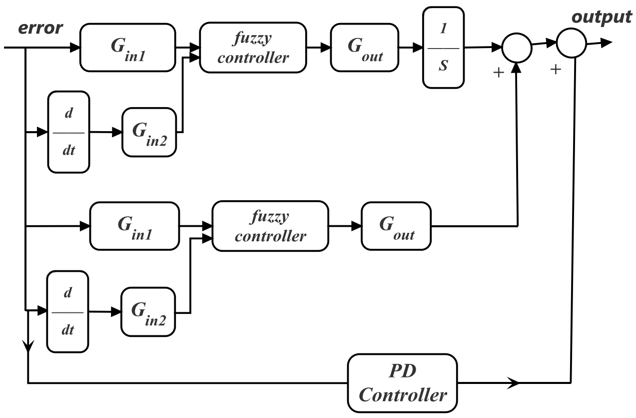

Figure 7: Fuzzy-PI with PD controller

The rules bases of fuzzy controller is shown in Table 1, which uses means of maximum (MOM) of defuzzification process. The scaled Gin1, Gin2, Gout, PI and PD are optimized using the PSO algorithm.

V. Results and Discussion

The simulation has been done using the MATLAB software in order to investigate the effectiveness of the proposed method in terms of system performances. As the first step, the system parameters for optimization are shown in the Table 2.

TABLE 2: DATA OF SYSTEM

R1= R2	T_{G1}= T_{G2}	T_{T1}= T_{T1}	T_{P1}= T_{P2}	K_{P1}= K_{P2}	T12	B_1= B_2
2.4	0.08	0.28	18	120	0.08	0.425

The bird step = 50, c2 = 0.01, c1 = 0.01 and ω = 0.09.

Then, the boundaries of G and PI parameters for optimal search are as follows:

0.01 < Gin1 < 10; 0.01 < Gin2 < 10; 0.01 < Gout < 10; and 0< PI/PD < 5.

A. Hybrid of fuzzy-PD with PI controller

To validate the effectiveness of the addition PI to the scaled fuzzy-PD controller, multi values of PI have been added to the scaled fuzzy controller as shown in Figure 8.

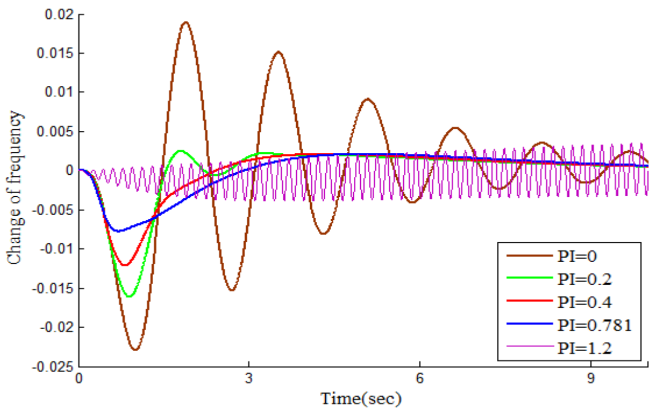

Figure 8: The effectiveness of adding PI controller

The effectiveness of adding the PI controller to scaled fuzzy controller is on the peak under shoot of 5% load changes which summarized in Table.3. It has shown that by adding the PI controller, the peak under shoot can be reduced significantly. However, it will become unstable for the PI gain value is too big.

TABLE 3: EFFECTIVENESS OF ADDING PI CONTROLLER

PI value	*0*	*0.2*	*0.4*	*0.834*	*1.2*
Peak under shoot	*0.0078*	*0.0054*	*0.0041*	*0.0025*	*Unstable*

The proposed controller is designed and compared with the scaled fuzzy controller and the conventional PID controller for LFC under system uncertainties. The multi small changes of disturbances with respect to the operation conditions are applied as shown from Figures 9 - 11.

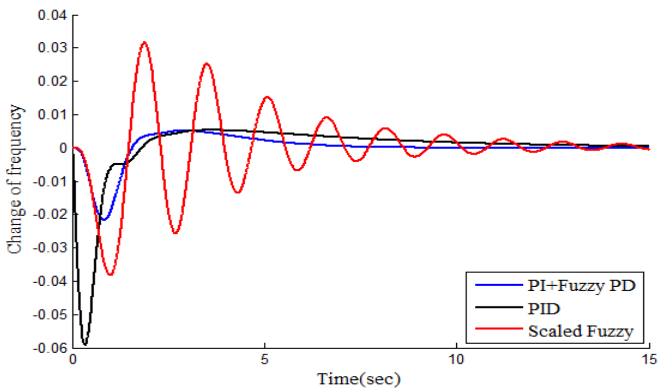

Figure 9: Frequency deviations of 1% load changes

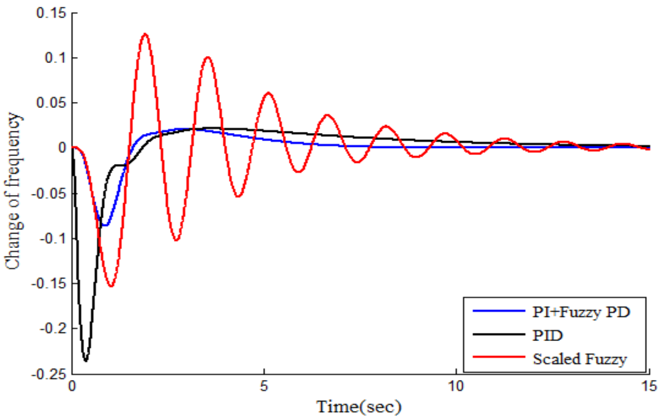

Figure 10: Frequency deviations of 2% load changes

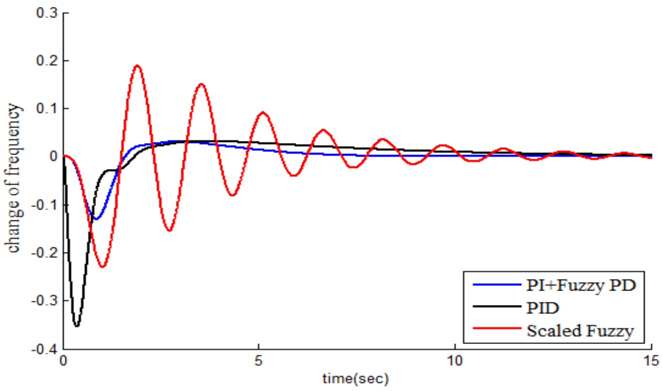

Figure 11: Frequency deviations of 3% load changes

From the results obtained, it can be summarized as listed in Table 4 for frequency deviation of peak under shoot (P.U.S) and settling time (S.t). It has shown that the scaled fuzzy PD hybrid with PI controller (proposed controller) has a trade offs advantage on the peak under shoot and settling time for load changes 1 - 3% with PID controller. However, for load change 4 -5%, the proposed controller has a superior performance compared with scaled fuzzy and PID controllers.

TABLE 4: COMPARISON OF PROPOSED CONTROLLER WITH SCALED FUZZY AND PID CONTROLLERS

L.Ch%	***PID controller***		***Scaled controller***		***Proposed controller***	
	P.U.S	***S.t(s)***	***P.U.S***	***S.t (s)***	***P.U.S***	***S.t (s)***
1	*1.18*	*9.14*	*0.793*	*13.43*	*0.254*	*9.24*
2	*2.32*	*9.1*	*1.54*	*12.91*	*0.491*	*9.31*
3	*3.5*	*9.21*	*2.4*	*12.31*	*0.7*	*9.32*
4	*4.7*	*9.33*	*3.2*	*11.82*	*1.01*	*9.3*
5	*6.8*	*9.38*	*4.8*	*11.51*	*1.7*	*9.11*

B. Hybrid of fuzzy-PI with PD controller

To validate the effectiveness of the additional of PD controller to the scaled fuzzy-PI controller, the multi tuning gain values of PD controller have been applied as shown in Figure 12.

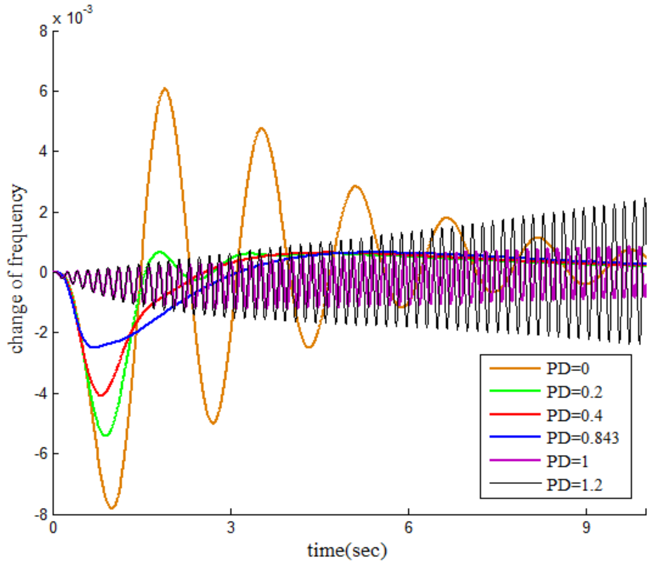

Figure 12: The effectiveness of adding PD controller

The effectiveness of adding PD controller to the scaled fuzzy-PI controller has been summarized the analysis on the peak under shoot for 0.25% of load changes as shown in Table 5. Same with adding PI controller, the peak under shoot and settling time have significantly reduced follows with the increment of PD values. The response becomes unstable when the PD value goes to 1 and above.

TABLE 5: EFFECTIVENESS OF ADDING PD CONTROLLER

PD value	*0*	*0.2*	*0.4*	*0.781*	*1.1*
P.U.S	*2.34*	*1.67*	*1.123*	*0.773*	*Unstable*
S.t	*14.15*	*8.21*	*8.24*	*8.246*	*Unstable*

Then, the proposed controller is compared with scaled fuzzy and PID controllers for LFC under system uncertainties (robustness of load changes) with multi operation conditions as shown from Figures 13 - 15.

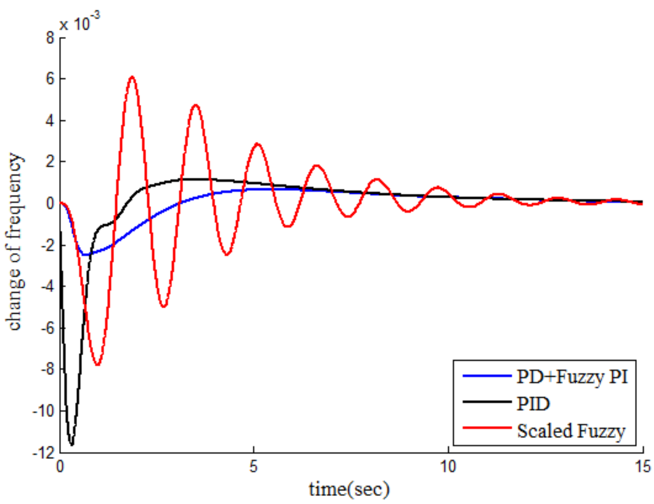

Figure 13: Frequency deviations of 0.1% load changes

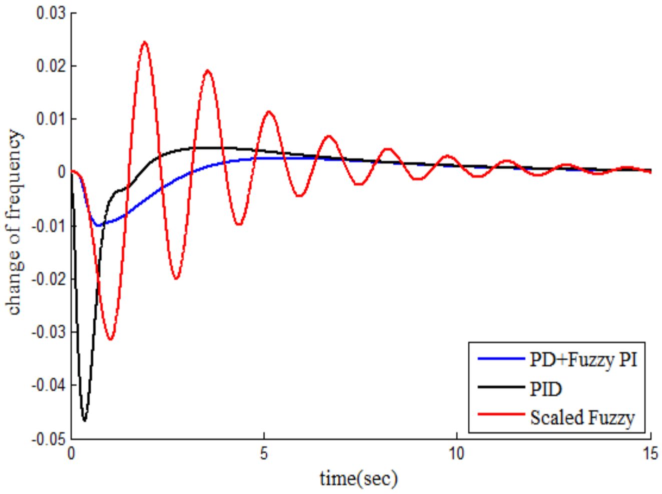

Figure 14: Frequency deviations of 0.25% load changes

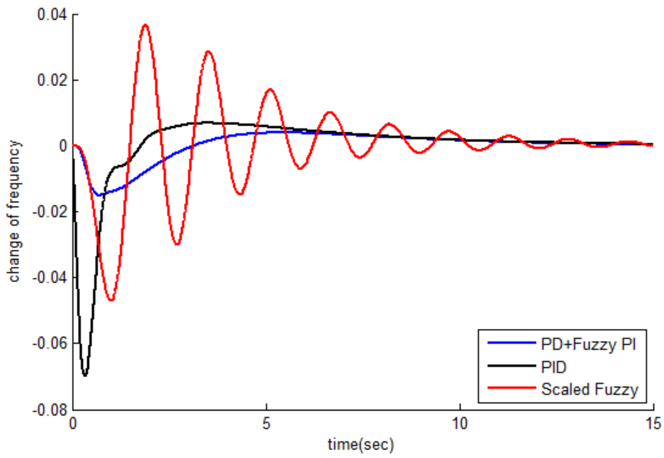

Figure 15: Frequency deviations of 0.35% load changes

As a result, a summarized of the responses performance have been wrote in Table 6 that showing the frequency deviation of peak under shoot (P.U.S) and settling time (S.t) for all comparison controllers. It can be seen, as overall, the proposed controller performs good performance responses when compared to scaled fuzzy and PID controllers.

TABLE 6: COMPARISON OF PROPOSED CONTROLLER WITH SCALED FUZZY AND PID CONTROLLERS

%L.Ch	*PID controller*		*Scaled fuzzy controller*		*Proposed controller*	
	P.U.S	***S.t (s)***	***P.U.S***	***S.t (s)***	***P.U.S***	***S.t (s)***
0.10	*0.0186*	*7.81*	*0.0132*	*13.92*	*0.0071*	*8.11*
0.25	*0.0479*	*6.96*	*0.0326*	*12.11*	*0.0993*	*7.01*
0.35	*0.0681*	*6.33*	*0.0476*	*13.24*	*0.0131*	*6.34*
0.45	*0.0802*	*6.35*	*0.0596*	*12.61*	*0.0184*	*6.37*
0.50	*0.0847*	*6.19*	*0.066*	*12.32*	*0.0197*	*6.21*

Finally, from results obtained, the proposed controller can be concluded has better performances than the optimized PID and scaled fuzzy controllers at all operating conditions. Therefore, the performance comparisons among all controllers indicate that the frequency response has approximately equal settling time (except for scaled fuzzy controller) but much reduced on undershoot for proposed controller.

VI. CONCLUSION

In this paper, two areas of power system have been used as a test system for the proposed LFC controller. Each area consists of three first order transfer functions of turbine, governor and power system interconnection. With taking the advantages of the simplicity of the PI/PD controller and non-linear adoption for fuzzy control, the proposed controller for FLC are developed. Then, in order to ensure the optimum responses of system performances, the scaled and gains tuning are optimized by using PSO. As for verification, the simulation results have obtained promising outcomes for the proposed controller.

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